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Engineering the learning experience: Influences and options

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Abstract: Specific graduate characteristics have been at the heart of important drivers such as the Engineers Australia Changing the Culture paper. Through the accreditation process, the need to identify and teach these characteristics began to shape the curriculum in many ways. How did this issue impact on the design of engineering curricula and how much flexibility could be afforded in responses to market demands or niche development?

One of the choices often encountered when designing engineering curricula is whether students should be offered a program that allows broadening of their skills and knowledge, or that provides opportunities for in-depth specialisation. Mechanisms such as offering Minors and Majors, workplace integrated learning and on-line resources can be utilised to achieve either of these approaches. Various external and internal influences affect curriculum design. Among the external influences are resources, government decisions, the profession's and industry views and assessment, Engineers Australia accreditation, word of mouth reputation in community, diversity in cohort, and how students choose institutions. Staff cultural issues and individual academic interpretation of goals and delivery appear to be among the top internal influences. There are also many other internal factors including time and resources, faculty structure and leadership, council decisions, as well as university reputation, but particularly the impact of the present engineering skill shortage in Australia and globally.

We explore such influences and the consequent program design decisions. The paper investigates some options for designing the learning experience and how these options are affected by focus on the curriculum itself or on the graduate.

Keywords: Engineering curriculum, learning experience, engineering skill shortage.

Introduction

Engineering education continues to re-invent itself not only in its response to various pressures, but also in its attempt to positively influence the next stages of technological advances and of enhancements of the quality of life in the community. Rapid technological advances are not the only factor affecting the design and implementation of engineering programs and the learning experience of engineering students. A quick examination of the literature on engineering education over the past few years reveals that there has been much thought and action in engineering education (Director *et al*, 1995, De Graaff and Ravesteijn, 2001, Hira, 1996, Berggren *et al*, 2003, Grimson, 2002, Mitra, 1997). For example, Grimson (2002) reports that universities and professional bodies throughout the world have recognised the challenges facing engineering education in the latter part of the 20th century and are engaged in major overhauls of the way in which they educate their engineers. He argues that there is widespread agreement that the engineering science approach, which for over 50 years has provided graduates of high technical ability, should be re-examined in the light of the needs of the 21st century.

As another example, Director *et al* (1995) gave a thorough treatment of how Carnegie Mellon University re-engineered the undergraduate electrical and computer engineering curriculum. The significant question they faced was "why change?" The paper lists a number of concerns or influences that drove the department to form a new curriculum. Among these were; emphasizing engineering ideas over techniques, support for interdisciplinary studies, and rationalisation of the requirements for topical coverage and workload.

An important driver which has attracted particular attention of late is the realisation and recognition of a global engineering skill shortage (Department of Education, Science and Training, 2005). The shortage is acknowledged at both technical and professional management engineering levels. However, there is evidence accumulating that, contrarily, many school students do not see engineering as an attractive career choice (Raison, 2006). Consequently, we are faced with the dichotomy of a declining intake into engineering programs, in a general sense, and yet a significantly increased demand for graduates. On top of that, the demand for graduates is variable in that it has both discipline and geographical contexts. Drivers for this demand include large infrastructure development for areas of high population growth such as a AUD66b plan for South East Queensland over the next 20 years.

At the technical level, the skill shortage is across all disciplines (Queensland Major Constructors Association, 2006). Driven largely by infrastructure projects, professional engineering skills are in high demand in civil and electrical (power) engineering, and those of allied disciplines. Coincidental to this demand is another driven by the increasing pressure on precious resources such as water and fossil fuels. The situation is further exacerbated by an aging workforce leading to many practitioners retiring over the next decade or so (Taylor, 2006), and the latency through undergraduate programs (normally four years).

In the following sections we will explore these and other influences in more detail together with some of the options open to designers of engineering programs.

Influences

In considering all the factors that influence the design of engineering programs and of the learning experience of students in those programs, we developed the diagram shown in figure 1. Internal influences are shown in the inner circle while the external ones are placed closer to the outer circle. The diagram also indicates that these influences are not totally independent from one another and that their effects on engineering the learning experience do not necessarily carry the same weight.

In February 2006, we participated in a Teaching and Learning Forum held at the University of Western Australia, Perth. At that forum, we conducted a half-day workshop addressing issues related to the design of the learning experience for engineering students comparing the ramifications of focusing on the program as opposed to focussing on the graduate. During the workshop, participants discussed, identified and classified internal and external influences on the design process and outcomes, from their perspective. These influences were classified in terms of their importance or strength of effect. The results of this discussion are presented in figure 2 below, which has features both similar to and quite different from figure 1.

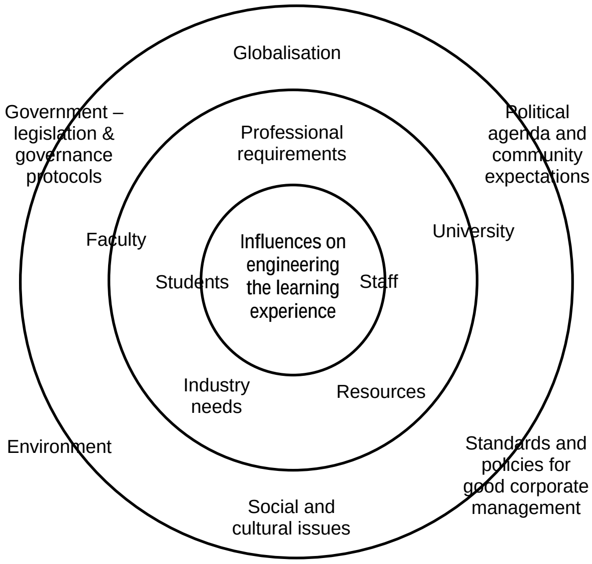

Figure 1: Our view of factors influencing engineering programs

The particular factors one could identify, and the degree of influence those factors have on one's engineering program, will vary between academics and between the institutions in which those academics work. This breadth of opinion underlies both the complexity and richness of the debate about how engineering programs should develop to acknowledge societal, professional, institutional and governmental changes. These matters provide the backdrop to the discussion on the internal and external influences in following sections.

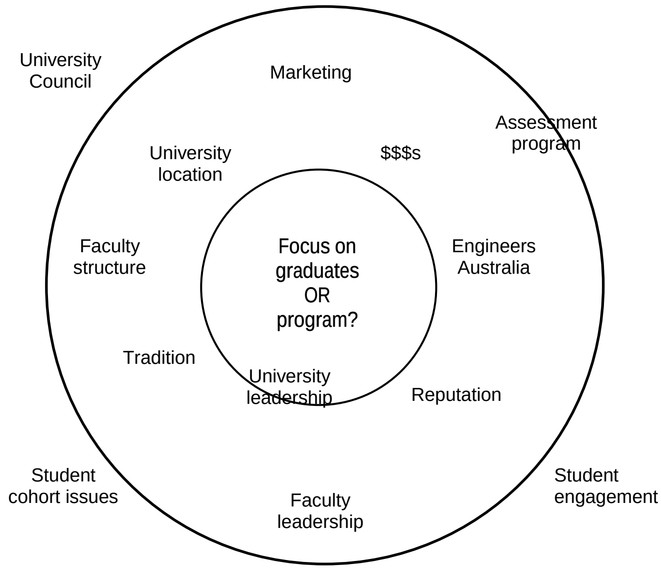

Figure 2: Workshop participants' views of factors influencing engineering programs

Internal Influences

Internal influences that impact on program design are those which are within the bounds of the University environment, and include staff and workplace culture, facilities, finance, faculty structure and leadership, University reputation, University location, student capabilities and their engagement. There is an increasing need for the staff culture to be less insular and introspective, towards one of greater innovation, responsiveness, and creativity; this is the focus of Engineers Australia's decade-old review of engineering education and is crucial to the design of new programs (Institution of Engineers, 1996). The quality and age of the teaching facilities is also important. Invariably well equipped engineering schools would design programs with a focus on a 'hands on' practical approach to learning. The history of development of the institution and/or the school or faculty has a strong bearing on program directions and operation. For example, in 1991 at QUT, the engineering schools were merged with others to become the Faculty of Built Environment and Engineering. Then more recently a major restructure combined the electrical and mechanical engineering schools to become the School of Engineering Systems, however civil engineering was placed within the School of Urban Development. These sorts of alliances and shifts can have both positive and negative influences on program design. Finally, the incoming students can have impact, including the technological savvy of the current generation, the level of their knowledge and skills, the degree of engagement required to motivate them to learn, and so on. They may need a learning environment that we cannot provide at present. Furthermore, many current students are supposedly full-time but are in fact are mixing part-time learning with part-time work.

External Influences

Governments of all persuasions can exercise significant control over the internal factors that impact ultimately on subject and program design, the most important government controls being budgets and legislation. As far back as 1972 in Australia, the Whitlam government changed the face of tertiary education through its free education policy and through the consequent dramatic increases in funding (Spies-Butcher, 2004). Very quickly academics found themselves having to redesign programs to cope with large increases in student numbers. Programs also began to change because commencing students had lower levels of knowledge and skill compared to the more elite cohorts of the past.

The late 1980s saw the second major shift in program design when the then minister for education, John Dawkins abandoned the binary system of colleges and universities (Conway, 1994). Many engineering programs in colleges began to be dramatically affected by the ensuing funding changes as teaching-centred colleges became research-hungry universities. More recent funding constraints exercised by the current Howard government have seen many engineering programs reduced to 4 subjects per semester with just 16 hours of formal class time per week. The inevitable loss of rigorously explored content is beginning to be felt, and commented on, by industries employing engineering graduates.

In the midst of, and often due to, government legislative changes, cycles in the national and state economies often have a dramatic impact on programs, in a manner similar to government funding changes. High demand from incoming student can mean a lot more students in classes, which leads to a heavier demand on the teaching staff in a given program, but also to more funds and therefore to the appointment of more academic staff. Alternatively, the academic cut-off score on incoming students can rise, leading to a more academically capable cohort and a perception by academics that more content can be taught to these students. However, when these economic cycles have a period only a few years long, the roller-coaster effect on student numbers, employment of graduates, and budgetary problems for an engineering school can be dramatic and distressing. Attempting to design effective, quality-driven and sustained programs in such an environment is very difficult.

From a professional point of view, however, the interdependent influences of Engineers Australia (EA) and of engineering employers are among the most significant factors affecting program design. Academics tend to view EA almost as a benevolent Big Brother – EA's imprimatur of accreditation is viewed as a non-negotiable outcome towards which all program changes must be driven, but by and large EA is also seen as a helpful partner in the process. Employers are viewed in a similar light by academics, and quite some effort is applied to understand employers' needs and opinions through surveys, industry advisory meetings, and ad hoc comments from personal professional contacts. Within these constraints, however, lecturers find themselves retaining an acceptable degree of independence and scope for innovation in most of the details of content and delivery.

Looking beyond university educational and budgetary issues, we find that many societal factors impact upon the number of students entering a program, upon the quality of the academic skills of those students and therefore potentially upon program design. Potential students and their parents consider the accessibility of the campus they will be studying at (public and private transport), the employability of graduates from the program, word of mouth comments circulating within the local or larger community regarding the quality of the program and how "work-ready" graduates are, overall job prospects nationally and locally, and so on. It's very difficult for individual academics or even engineering schools to change any of those factors, however, efforts to engage the community and high schools in activities that give a taste of engineering can pay dividends in terms of reputation and friendliness.

Options

Given the internal and external influences discussed above, there are various options for engineering the learning experience. These options provide multiple ways of producing graduate engineer with specific skills and attributes, through the realisation of certain learning outcomes. Engineering program designers have a number of general principles or constraints guiding their decisions, especially those of accreditation as described earlier. EA's flexible approach to accreditation, however, leaves the door open for various philosophies to be utilised as bases for engineering the learning experience. Let's now consider some example options and later discuss their effects on the graduating engineer.

Content or Capability

Whenever the opportunity to design a new program arises, academics tend to focus on the technical content. The argument put forward is that engineers need to have the discipline knowledge necessary to carry out the design, innovation and maintenance work expected and required of them. Serious debate often takes place which tries to address the choice of discipline knowledge that must be part of the program. Some academics insist that their own areas of discipline knowledge are essential for the program (Director et al, 1995). Program designers find themselves in situations where, if they satisfied the requirements of all staff, they would end up with programs that are "crowded" with content, without the necessary balance and relevance expected in a graduating engineer.

This is often at odds with the view that a program should be designed with a focus on the professional capabilities that graduates must be able to demonstrate upon graduation (Graaff, 2001); by "professional" we mean those transferable skills every university graduate, including engineering graduates, is expected to demonstrate. Preferably, these capabilities should be built within and around the technical content; the identification and selection of capabilities and content to be taught should be interdependent. All universities have developed very similar sets of professional capabilities that supposedly characterise their graduates, with differences in the capabilities more in the emphasis and fine details. Programs designed with the professional capabilities as the focus often use the discipline content as the "vehicle" around which the capabilities are built.

Workplace Integrated Learning (WIL) is an increasingly employed mechanism to provide contextualised engagement in learning, to provide greater opportunity for work-ready preparedness, and for students to develop integrated technical and professional capabilities. This naturally requires serious commitment from universities, students and industries in allied engineering fields. This in itself creates an extra burden on industry supervisors and resources. Some engineering companies enthusiastically embrace work place integrated learning programs, and the underlying pedagogy, thereby providing valuable educational outcomes for all concerned. However, an increasing shift to WIL modalities of program delivery, requires a cultural shift to increase the hosting capacity of industry as a whole.

Broad Content or Specialization

Program designers may choose to build a more specialised, narrowly focussed experience as opposed to one that provides a broad curriculum. In support of the former option, some argue that, due to rapid technological advances, engineering curricula need to provide enough depth in specialised areas to enable graduates to readily contribute to these advances. The argument for this approach continues to point to the need for some graduates to be prepared for research work, whether in industry or in academia. But, more often than not, program designers face serious difficulties getting academics to agree on what constitutes the "most important" or "essential" areas of these specialisations, with each attempting to make the case for their own area of expertise. This can easily lead to too many topics being covered in a program, defying the very argument for depth and specialisation. Any attempt to reach consensus on a minimum set of advanced topics to mandate in a curriculum rapidly yields a huge and unwieldy set of "essential" classes (Director et al, 1995).

The option of broadening the curriculum often draws on the idea of providing a "holistic education" in order to mandate a percentage of the overall program to be dedicated to subject areas outside "traditional" engineering curricula. Such approaches often promote the use of Minors and Majors. However, even if this path is taken, a range of options still exists from mandating that Minors must come from subject areas that are totally outside the engineering discipline, to mandatory Minors based on cognate areas of specialisation.

Other options and considerations

Not only are there options to consider with respect to the design of a whole program, but also in designing parts of program. For example, the first year experience can vary enormously depending on whether the new students are faced with subjects that focus on specific disciplines, or experience a common year for all commencing engineering students within the one faculty (Berggren et al, 2003). Such options have ramifications that go beyond the first year experience to affect the way the rest of the program is designed, with consequential effects on the graduating engineer.

Regardless of whether curriculum designers decide to focus on technical content or more diverse skills, on the one hand, or on broad or specialized content, on the other, learning outcomes will not be influenced by course content only, but also by the adopted pedagogy. The options presented here should not be considered in isolation from an implementation strategy which should encompass the strategic, tactical and operational dimensions. Neither should these options be seen as independent from the critical value that quality teaching staff can bring, or the importance of providing students with quality support systems and services.

Beyond the options presented here, there are various implementation possibilities that can also affect graduates. For example, assessment is a vital factor in influencing what and how students study but can vary widely even within one program. Vigorous discussions surround comparisons of norm-based assessment with criterion-based assessment, which in turn feed into how programs are designed and their outcomes evaluated.

The focus on the graduate or the program itself, as the central element in designing a program, will add yet another layer in utilising whatever options considered for engineering the learning experience.

Engineers, Programs, What's the Focus?

A question that regularly challenges Engineers Australia's panels of accreditors and of the profession at large is, "what is an engineer?" A recent instance of this was the issue of whether to accredit software engineering programs – did those trained in such programs actually produce engineering services or products in the traditional sense or was this something new that stretched the bounds of engineering?

These debates are important for the profession because the boundaries between the so-called traditional areas of practice have in fact always been changing. Originally there were military engineers and those who weren't – they were called civil engineers, though their activities encompassed much more than what civil engineers do today. The non-military branch steadily split into civil (as we know it today), mechanical, electrical, production, manufacturing, power, environmental, construction, etc, etc.

Because society is constantly changing in its structure and needs, and the technologies and processes for satisfying those needs never sit still, we must continually revisit the definition of engineering and of the ill-defined and often arbitrary divisions between specialisations.

A recent development is the rise of an informal international fraternity of "engineering systems" interests. This is a different focus from the more well-known and long established systems engineering area. Engineering systems is much broader and rather than producing a new and separate branch of study, is more of a synergistic bringing together of those interested in a holistic rather than particulate view of engineering. This move is reflective of an understanding among many that the practice of engineering is best viewed as a constantly shifting continuum rather than well-defined boxes of static specialisation.

The impact of these debates and developments on those trying to design programs is enormous. Employers want graduates who are work-ready, who are technically knowledgeable and skilled in the particularities of the employer's field of activity, but who have generic capabilities and business acumen honed and ready to adapt to any changes that employer may adopt. The goal posts for program designers are indeed constantly changing.

An even greater challenge to designers than the increasing uncertainty of the requirements and desires of the profession and industry is the matter of whether academics are supposed to produce an educational product that students purchase to become engineers, or whether academics are producing engineers who are purchased by employers and recognised by the profession. In other words, the question is: are we designing programs or engineers? Employers would answer “engineers”. Accrediting bodies would answer “programs that produce engineers”. University administrations would answer “programs that attract students”. These are demands that pull in different directions and are often hard, and sometimes impossible, to satisfy simultaneously.

So, academics certainly need to be fully aware of these various demands and of their current status and directions and constantly debate the associated issues within academia. But furthermore, they must take the lead when necessary to help employers and the profession to appreciate the need for novel ways of delivering programs, to allow for shifts in content within those programs, and even to accept brand new program structures and focuses that will better prepare graduates for life as an engineer, whatever that is!

The Way Forward

The discussion above showed there are many influencing factors within and beyond a program and a university, together with philosophical issues driving decision making, all of which impact upon the product of engineering education, whether that product is the graduate or the program.

But what about the future? Will these factors and influences continue to affect program design and the quality of graduates and the professional development of undergraduates in the same way as at present? Will the trend in the present skill shortage evidencing itself disparately around Australia and internationally continue upwards or disappear in a few years? What will universities themselves look like 10 years from now? Will they be overtaken by the commercialisation and “virtualisation” of tertiary education?

These are important questions because one can’t train engineers in a day – it’s a long term investment by the community that is not finished upon graduation from 4 years of hard study but rather has just started. Engineers need to be trained to deal not only with rapid changes in technology but also with stable societal needs that persist often for decades or centuries. As academics we attempt to produce graduates who are not only able to adapt to constantly changing materials, processes, and products, but can also recognise the long-term effect of their decisions on both the urban and green environments. The objective is not only to help undergraduates become work ready on graduation but also to become reflective practitioners who are lifelong learners and have professional principles that will ensure the local and global communities are served ethically and in a sustainable way. Engineering education must have a far-sighted view of the world and be cognisant of and prepare for the vagaries of the future.

For example, presently there are huge public investments in infrastructure in Queensland and Western Australia in which many billions of dollars have been planned to be spent over decades on serving booming state economies and burgeoning populations. However, in the southern states of Australia, state government budgets are much more constrained due to post-mature economies that are not resource-rich and due to populations that are growing only slowly or even shrinking. The demand for engineer graduates is therefore currently insatiable in the north and west of the country but there’s perceived to be something of an oversupply of graduates in the south. This situation is not likely to change for the next 10 years or more, so should policy makers and budget officers and program designers assume that staffing levels and profiles and numbers of students entering a program must respond appropriately?

The answer to this question is difficult because the current scene could change quickly. Many of the major infrastructure systems in southern states are aging badly, with portions of the sewer systems in Melbourne and Sydney, for example, being over 100 years old and in desperate need of replacement or at least of massive rehabilitation. Successive governments have mostly overlooked the problem, hoping it will all hold together while they are in power – this attitude is likely to continue for some time because of the enormous budgetary implications. But if there was a serious collapse of a significant proportion of a vital piece of urban public infrastructure in the southern states, the consequences could be widespread and not quickly rectified. Such a collapse could generate urgent calls for major government expenditure and could change the geographic distribution of demand for engineers.

There are two other major uncertainties impacting on clear decision making by program designers. The first uncertainty is any major shift in federal government policy. Universities have seen themselves as the guardians of knowledge, of research, of professional standards, and of higher education itself; governments have tended to support that view through public funding and restrictions on use of the title “university”. However, there is a belief amongst some politicians that this approach is restrictive and that education should be subjected to the same open commercial basis of operation as any other business activity (after all, education in Australia is the 2nd largest earner of national export income). Where would the future of engineering education lie and how would professional accreditation respond should any profit-driven organisation with sufficient funds be allowed to set itself up as a university and offer BE degrees, without the current governmental controls? The oversight functions of Engineers Australia would become critical in such situations and national accreditation of engineers in a manner similar to the “RPEQ” requirement in Queensland could be vital.

The second uncertainty is the “virtualisation” of education. Tertiary teaching especially has for some years been challenged by the flourishing range and capabilities of online teaching products and content, let alone by the possibilities that may lay in the rapidly developing hand held devices that combine the functions of a PDA, mobile phone, MP3 player, internet access, and so on. Why should students come physically to a campus? The in-class experience is being pressured heavily to acknowledge alternate learning technologies and make face-to-face activities more than just content delivery. Students are already “voting with their feet” when they see they can get much of the content online instead of sitting for hours listening to lectures delivered from a text book. The times are nearly over in which program designers could assume the bulk of a student’s learning will take place in traditional lecture/tutorial/laboratory physical spaces (that is, if it ever did!). But how that learning will take place and what is the consequent “right” form of design of a program, is very unclear and is still being debated hotly all around the globe. Every time some degree of clarity appears, a different technology emerges to de-emphasise or even make obsolete all the work that has gone into adopting other technologies. What is certain, however, is that university teaching of engineering undergraduates must and will change, and continuously so.

Conclusions

This paper explored a number of influences affecting the design of engineering programs. It also gave examples of the options available to program designers. There is wide debate about what those influences are specifically, whether they are internal or external, and the degree to which they affect program designers. On the one hand, external influences are able to be swayed by academics only in a limited way, if at all, and can include government policy and budgets, campus accessibility, institutional reputation, accreditation, employer requirements.

On the other hand, internal influences are able to be swayed by academics more strongly and can include staff culture, faculty structure, institutional tradition and marketing, management, budgets, competing academic demands, teaching facilities, and staffing resources.

It is evident that program designers need to weigh up whether they are attempting to design a program that is attractive to incoming students, that satisfies employers and the institution, and that is able to be accredited by Engineers Australia, or whether they are attempting to produce an engineer who is work-ready, technically competent, professionally skilled and business-savvy.

While the current influences and options present some challenges and generate much discussion and debate, they also lead to more questions than they provide answers. Engineering educators, and particularly those involved in program design, face questions such as; will the current factors and influences continue to affect program design and the quality of graduates and the professional development of undergraduates in the same way as at present? Will the trend in the present skill shortage evidencing itself disparately around Australia and internationally continue upwards or disappear in a few years? What will universities themselves look like a decade from now, given the waves of the commercialisation and "virtualisation" of tertiary education?

It is argued that the various complex and multiple pressures both within and beyond a university's boundaries can exert strong influences over the design of an engineering undergraduate program. The discussions presented in this paper highlight the breadth of opinion which underlies both the complexity and richness of the debate about how engineering programs should develop to acknowledge societal, professional, institutional and governmental changes.

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